Micro-Synchrophasors for Distribution Systems

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Project Objectives
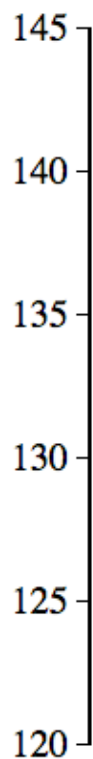
‣ Develop a network of high-precision phasor measurement units (µPMUs) to measure voltage phasors with unprecedented accuracy (~ 0.01°)

‣ Study diagnostic and control applications for µPMU data on distribution systems and develop suitable algorithms

‣ Challenges include multiple sources of measurement error and noise: learning what matters

‣ Performance metrics include angular resolution, overall accuracy, latency; key objective is to match data quality with applications

‣ Develop useful, practical tools for a new type of visibility and management of distribution circuits

Accomplishments

▸ Demonstrated µPMU device performance on lab bench

▸ Installed and networked prototype µPMUs at Berkeley Lab pilot site with 4G wireless communication

▸ Debugged hardware, firmware, installation design

▸ Built scalable database and plotting tool "Quasar 2.0" for fast and flexible access to high-resolution time-series data

▸ Prepared detailed installation plans with host / partner utilities at four field sites, targeting different applications

▸ Analyzed requirements and use cases for a broad spectrum of diagnostic and control applications

▸ Developed theoretical algorithms for topology detection, state estimation, fault location based on µPMU data

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Soda Hall Voltage (V)

145
140
135
130
125
120

Grizzly Voltage (V)

7,500
7,000
6,500
6,000

Alameda Voltage (V)

Legend

🟩	uPMU/upmu/grizzly_new/L1MAG	y2
🟫	uPMU/upmu/grizzly_new/L2MAG	y2
🟢	uPMU/upmu/grizzly_new/L3MAG	y2
🟦	uPMU/upmu/psl_alameda/L1MAG	y1
🔵	uPMU/upmu/psl_alameda/L2MAG	y1
🟦	uPMU/upmu/psl_alameda/L3MAG	y1
🟪	uPMU/upmu/soda_a/L1MAG	y3
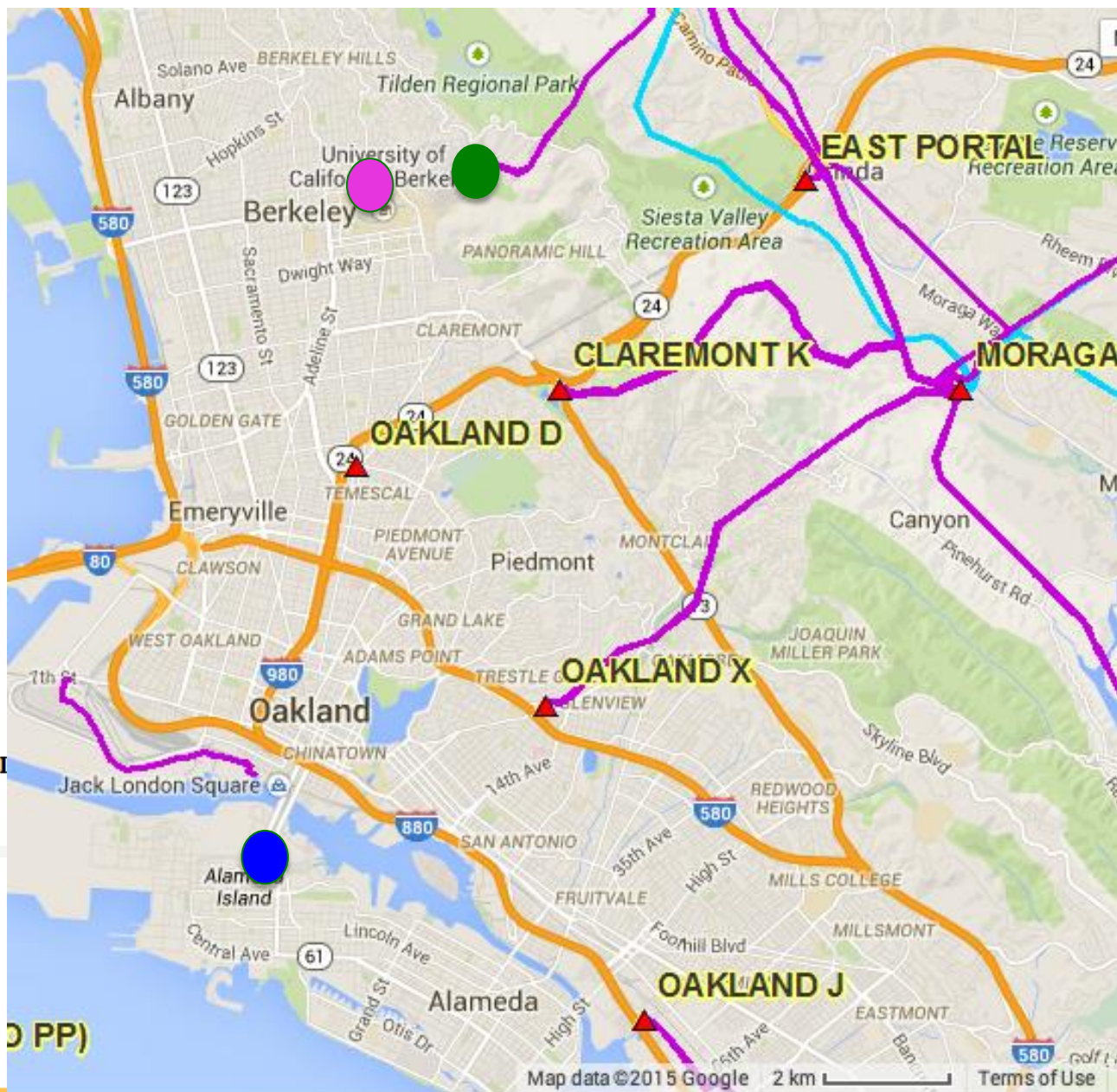
(Voltage scales adjusted)

Legend

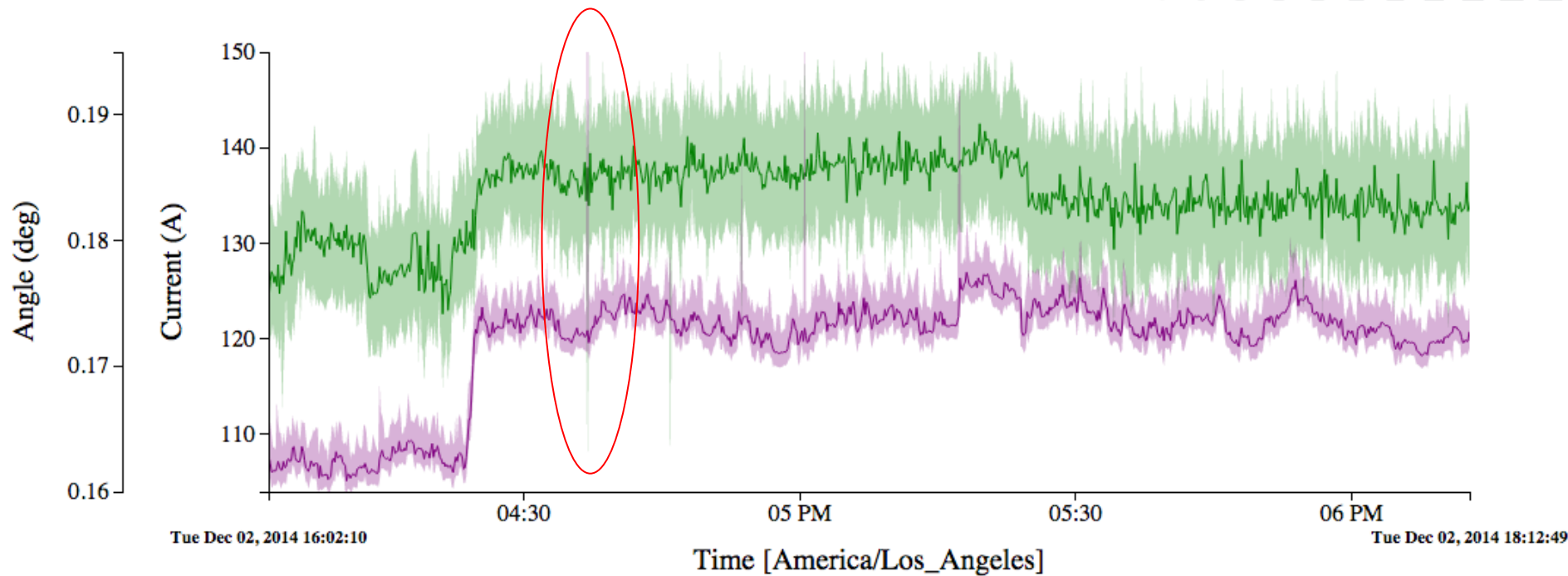|		
🟩 uPMU/upmu/grizzly_new/L1MAG	y2	⬍
🟫 uPMU/upmu/grizzly_new/L2MAG	y2	⬍
🟢 uPMU/upmu/grizzly_new/L3MAG	y2	⬍
🟦 uPMU/upmu/psl_alameda/L1MAG	y1	⬍
🔵 uPMU/upmu/psl_alameda/L2MAG	y1	⬍
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🟪 uPMU/upmu/soda_a/L1MAG	y3	⬍
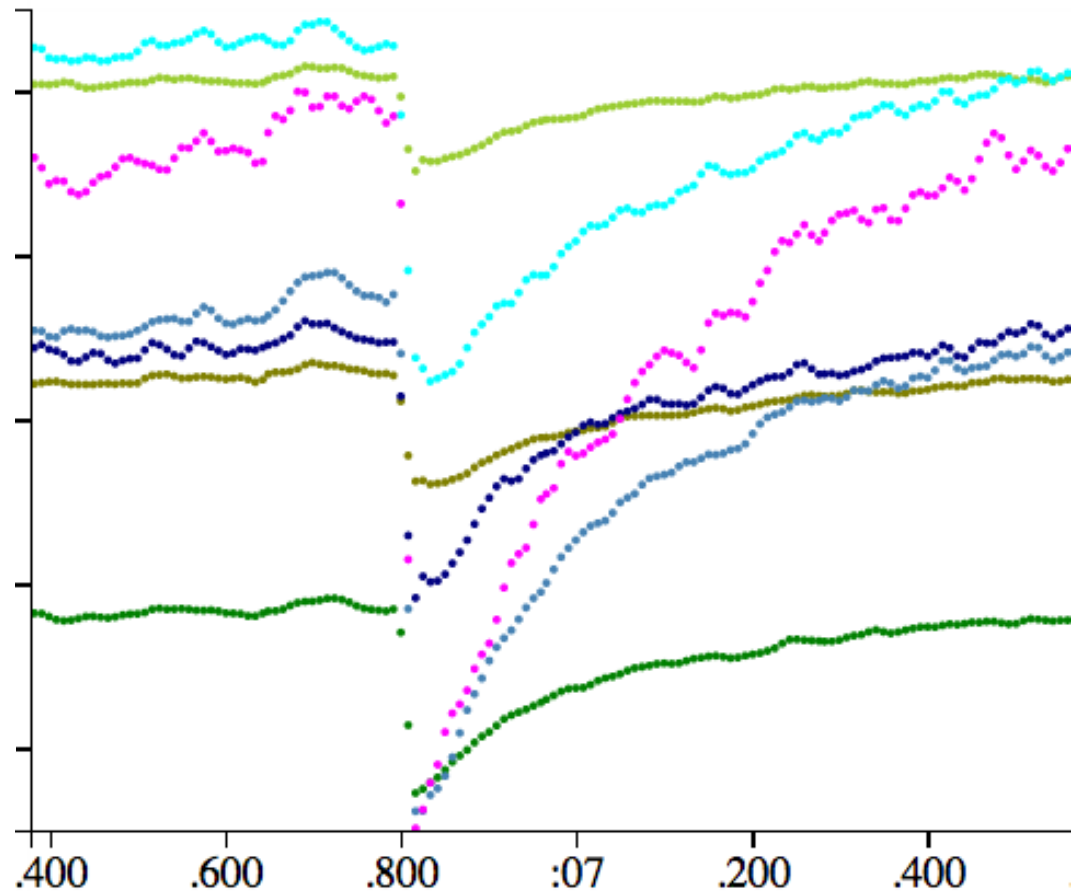
Synchronized magnitude measurements reveal phenomena common to different measurement locations.
This graph shows full resolution of 120 samples / sec.

Voltage phase angle difference (green) and current (violet) between two locations on a 12kV cable over a two-hour time period.

Plotter shows min-max-mean of 120 samples/sec data.

Legend

■ Distillate/Phase Ang Diff/Grizzly-Switch_a6/Grizzly-SwitchA6_VOLT_ANGDIFF_1
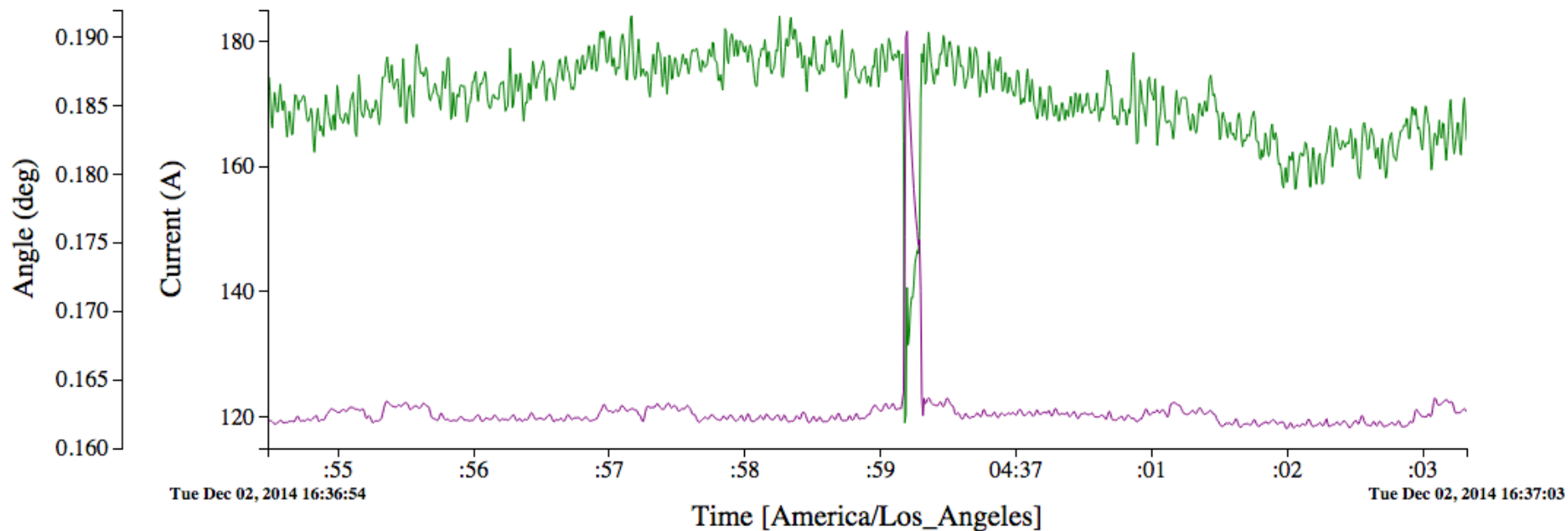
■ uPMU/upmu/switch_a6/C1MAG

Legend

- ■ (green) Distillate/Phase Ang Diff/Grizzly-Switch_a6/Grizzly-SwitchA6_VOLT_ANGDIFF_1
- ■ (violet) uPMU/upmu/switch_a6/C1MAG

Voltage phase angle difference (green) and current (violet) between two locations on a 12kV cable, seen at greater resolution.

In Progress

‣ Empirical data analysis: identify phases, power flows, interpret events…

   What's hard: small signal-to-noise ratio, identifying error sources (e.g. PTs & CTs)

‣ Validate circuit models: calculate impedances

   Pilot site has short, lightly loaded, asymmetrical underground cables

‣ Modify installation plans to allow more simple, direct validation at some locations

   It's hard to ground-truth field data absent other good instrumentation

In Progress

▸ Proceed with field installations

  Must address diverse utility criteria for hardware specs, tailor peripherals and placement strategy to specific environments, manage expectations

▸ Integrate new µPMU data streams and implement distillates on Quasar

▸ Perform state estimation and topology detection algorithm computations offline in Matlab environment

▸ As an alternate method, integrate C37.118 µPMU data stream with OSIsoft PI server, compatible with existing tools

▸ Continue theoretical work on control applications

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Technology-to-Market

▸ Targeting electric utilities, system integrators, microgrid projects and vendors of distribution controls for hardware sales

▸ Discussions with potential partners for software commercialization, which may include

  - new products based on open-source code developed by UC Berkeley

  - expansion of existing software products to integrate μPMU data

▸ Generally positive interest, especially international

▸ Challenge is to have persuasive empirical evidence in hand early in project

Objectives

▸ Complete field installations at manageable scale

▸ Demonstrate empirical μPMU data provide useful, actionable intelligence about the distribution system

▸ Exercise topology detection and state estimation algorithms with field data, evaluate performance

▸ Test algorithms for decentralized control of distributed resources based on μPMU measurements in simulation environment

▸ Identify most promising and fruitful directions for follow-on research, development and demonstration

Post ARPA-E Goals

▸ Significant work remains on developing μPMU applications, including

    - expansion and refinement of algorithms and software developed within this project, and

    - study of applications outside the scope of this project

▸ Control applications are likely a key area of interest, as the needs and opportunities for distributed control are growing

▸ Model-based vs. non-model based approaches to be compared

▸ Control applications will require extensive simulations as well as field testing to allow proper confidence

▸ Synchrophasors will be useless where transmission & distribution networks convert to d.c.

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Conclusions

‣ Distribution synchrophasors are an idea that is resonating well throughout research community and industry, esp. in California

‣ Scary data volume (terabytes) can be handled effectively

‣ Practical implementation of field measurements faces mundane, time-consuming hurdles

‣ Key remaining challenges for measurement accuracy reside outside, not inside μPMU

‣ Many advanced application opportunities appear worth exploring